ENERGY CONSCIOUS RESIDENTIAL DESIGN FOR A TROPICAL ISLE

American Institute of Architects
Guam and Micronesia Chapter

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Information contained in the book is based on public record, visual observation and descriptive material received from project designers. All reasonable attempts have been made to assure the accuracy of the facts and opinions contained herein. However, inaccuracies may occur and the authors suggest that all facts and opinions be verified before the reader relies on them in any manner.

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Introduction

Tropical isles can be idyllic and casual, yet present problems in developing truly comfortable and energy-efficient living conditions. Islands have the potential of being marvelous places to live. With sea breezes, moderate temperatures and plenty of sunshine, comfort depends upon the designer's ability to use these assets while carefully handling high humidity, heat gain and frequent rain.

This book is developed as a reference for energy-efficient design in residences. As a planning and design tool, it provides homeowners, builders and members of the housing community with an understanding of the conditions that affect buildings in the tropics; it provides basic background on the design factors necessary to construct comfortable energy-efficient homes.

The presentation is for three levels of review: the quick overview, general reading and detailed exploration of formulas and techniques. A quick review of photos, plans and sketches will provide a sense of the tropics along with several appropriate design ideas. A general reading will bring an appreciation and understanding of the interrelationship of human comfort design factors and how they apply to the island environment. The potential of good, appropriate design will become clear, and the individual house concepts can be studied, discussed and compared. Finally an indepth review of the formulas and calculations will present firsthand the intricacies of the refined application of detailed techniques.

The book is divided into six sections. The first two sections provide design criteria affecting all construction such as climate factors, site characteristics, heat gain concepts, daylighting principles and window and shading comparisons. These principles apply to each type of construction, whether naturally ventilated, air-conditioned or partially air-conditioned.

The specific application and principles of natural ventilation and air conditioning are discussed in the third and fourth sections. The fifth section deals with partial air conditioning by integration of air-conditioning and ventilation techniques to combine the benefits of each. The final section deals with specialized concepts of energy efficiency that may be applied along with the previous methods.

Emphasis is on the pragmatic approach to an individual's comfort and choice of housing. Natural ventilation is not for everyone, neither is total air conditioning. There are far too many examples of houses designed only for air conditioning which are later ineffectively converted to natural ventilation by opening the few improperly designed and located windows. The occupants swelter in poor ventilation and blame it on the climate.

There are an equal number of naturally ventilated structures with window air conditioners haphazardly scattered along the walls. The air infiltration is excessive and the condensation alarming, making the house feel cold and damp.

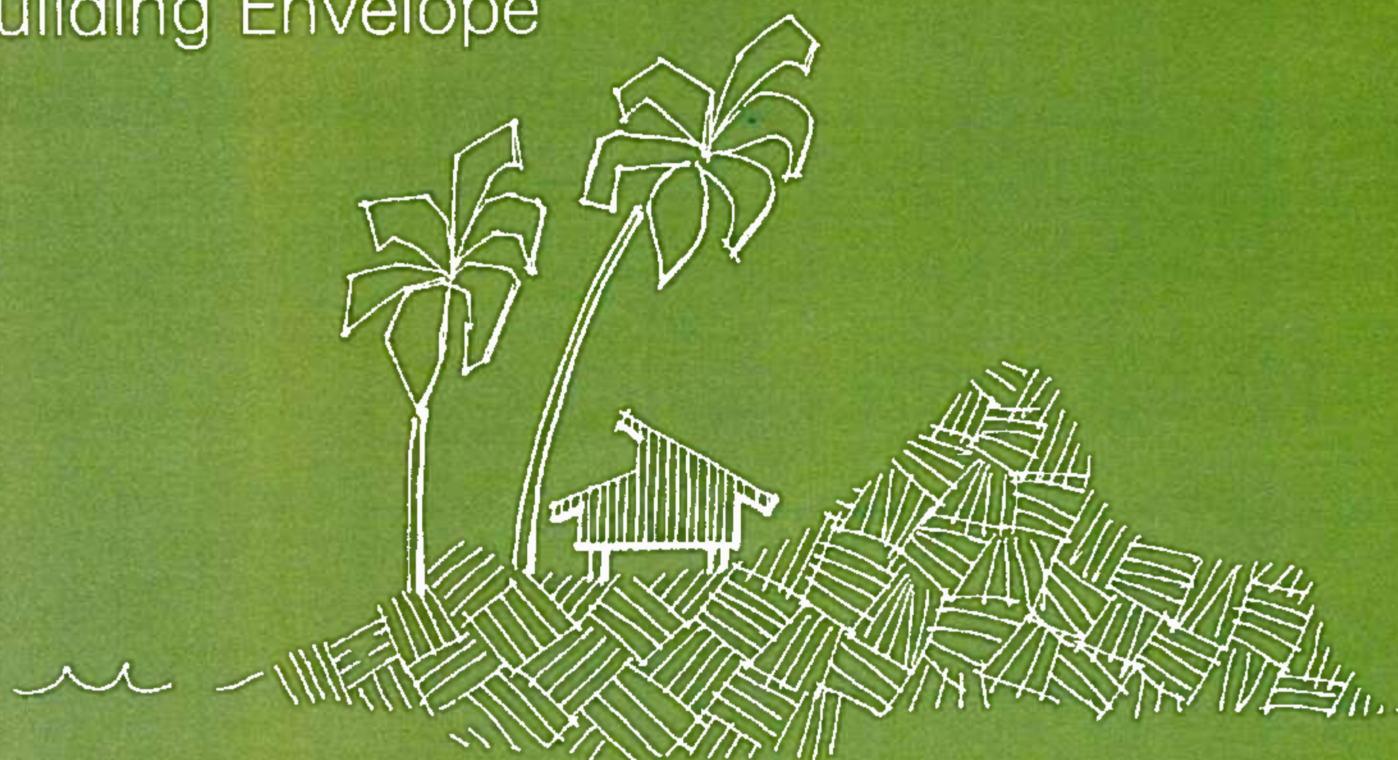
There are choices to be made that allow better flexibility. There is information available to allow owners a better understanding of the climate and what they will experience as comfort or discomfort prior to locking themselves climatically into a manmade prison. Concepts on this flexibility and pertinent facts on climate and human comfort are contained herein.

The book is structured to allow individuals to become more aware of the factors that influence the design and construction of their buildings and to allow them to participate in decision making. It is not a recipe book and all recommendations may not be appropriate to each individual case.

The overall message is for appropriate energy-conscious design. A key step toward assuring this appropriateness is to consult an architect, one sympathetic with the regional uniqueness of an island and with a thorough understanding of the energy-conscious principles contained herein.

It is advantageous to involve this architect in the early stages of the project to ensure planning does not become committed to solutions that may later prove difficult to implement or too inflexible to satisfy specific conditions. Construction is permanent and often a once-in-a-lifetime undertaking.

Chapter I
Design Comfort Part I
Climate
Microclimate
Heat Gain
Building Envelope



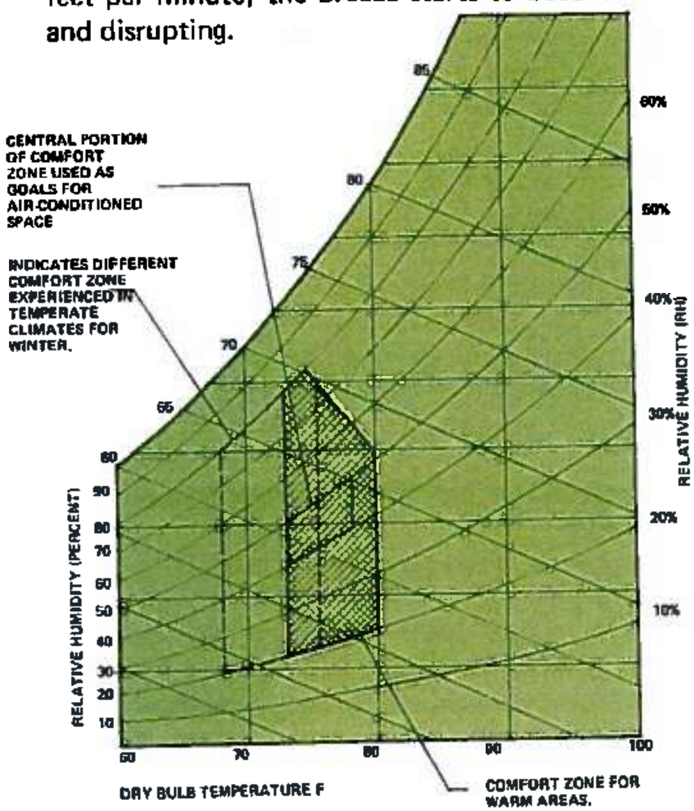
Human Comfort

Four major properties of the environment influence human comfort: air temperature, humidity, air velocity and radiant temperature.

Temperature: The degree of heat in a body or substance, such as air, expressed in degrees Fahrenheit (F) or Centigrade (C).

Relative Humidity (RH): The amount of moisture in air compared to the maximum amount that can exist at a given temperature without condensation, expressed in percentage.

Air Velocity: Movement of air through space, expressed in feet per minute (fpm) or miles per hour (mph). Ten feet per minute is considered stagnant and above 2-3 miles per hour (175-265 feet per minute) the breeze starts to become drafty and disrupting.



Radiant Temperature: Temperature of a solid object which emits or accepts radiant energy. Human skin temperature is about 92F (33.3C) when comfortable and radiates heat to cooler objects and receives heat from warmer objects.

When only air temperature and humidity are considered, the main part of the human comfort zone is between 72F (22.2C) and 78F (20C) with a relative humidity (RH) of 40 percent to 50 percent.

AIR MOVEMENT AT 1.7 MILES PER HOUR (150 FEET PER MINUTE)

Air Temperature	Effective Temperature
88	87
86	85
84	83
82	81
80	79
78	77

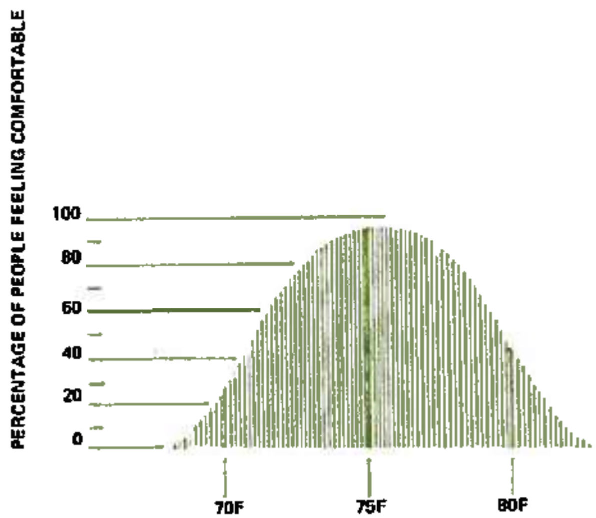
AIR MOVEMENT AT 4.5 MILES PER HOUR (400 FEET PER MINUTE)

Air Temperature	Effective Temperature
88	83
86	81
84	79
82	77
80	75
78	72.5
76	70

EFFECTIVE TEMPERATURES RESULTING FROM AIR MOVEMENT

The peripheral portions of the comfort zone include other combinations of relative humidities and temperatures. In general, if the RH increases, the temperature should decrease and if the temperature increases the RH should decrease.

The perception of temperature and humidity is affected by what is often referred to as the wind chill factor, a passage of air over the skin causing increased evaporation and making a person feel cooler. Thus, a person in a slight breeze feels comfortable in a higher combination of both RH and temperature.



40 TO 60 PERCENT RH
WITHOUT BREEZE OR COOL RADIATING SURFACES

THE ACTUAL COMFORT ZONE WILL VARY WITH THE INDIVIDUAL. THE MAJORITY OF PEOPLE FEEL COMFORTABLE WITHIN THE INDICATED ZONES. OTHERS FEEL COMFORTABLE AT STILL GREATER LIMITS.

The customary light, casual clothing of a tropical lifestyle aides temperature radiation and evaporation and contributes to human comfort under high humidity conditions.

Acclimatization is also a factor as people's comfort tolerance of tropical temperatures and humidity increases with their length of exposure to the climate.

Climate

A tropical island environment is warm, humid, and has a reasonably constant climate. The main climatic periods are the dry and wet seasons while the seasonal variations of temperate climates, winter, spring, summer and fall, are much less pronounced. For islands the surrounding ocean moderates the temperature. The tradewinds temper the impact of the relative humidity making the climate generally pleasant.

For an architect or someone planning a home, the key aspects of a climate are those which affect human comfort and the use of buildings. These include the averages, changes and extremes of temperature, humidity, winds, rainfall, solar radiation, sky conditions and specific site characteristics.

Wherever one lives in the tropics, local weather charts, along with sun data should be reviewed when designing a house. The weather information is usually available at regional weather facilities, airports and educational facilities. Sun charts depend directly on the latitude and are available from reference books.

The specific climatological data for our island, Guam, is included in the appendices.

Temperature

The overall temperature range in the tropics is generally at or above the upper part of the comfort zone. Islands in general benefit from the moderating effect of the surrounding water and both the overall daily temperature variation and seasonal variation will be less extreme than most larger land masses.

The location within the equatorial belt also affects the temperature range with less seasonal variation and slightly higher temperatures occurring closer to the equator.

Changes in temperature can actually be experienced on the same island. The higher elevations, particularly on the windward side of the island, high coastal plateaus and mountain crests are frequently cooler than inland and river locations where the temperature and RH are both higher. Low-lying and sheltered areas will also benefit less from the pleasant tropical breeze.

Relative Humidity

For many tropical locations, the high relative humidity is more of a nuisance than the temperature.

The concept of "relative humidity" provides a direct indication of evaporation potential. The warmer the air, the greater the potential for the air to hold moisture. Humidity is highest in the early morning, when the temperature is the lowest and the potential for the air to hold moisture the lowest, and decreases to its lowest point in the afternoon when air temperatures and moisture capacities are the highest. The afternoon values are much more characteristic and are often used alone as a brief indication of humidity conditions.

During the dry season the relative humidities are lower and approach those of more temperate islands such as Hawaii. Throughout the Pacific Basin these climatic conditions vary with the islands closest to the equator being slightly warmer and more humid.

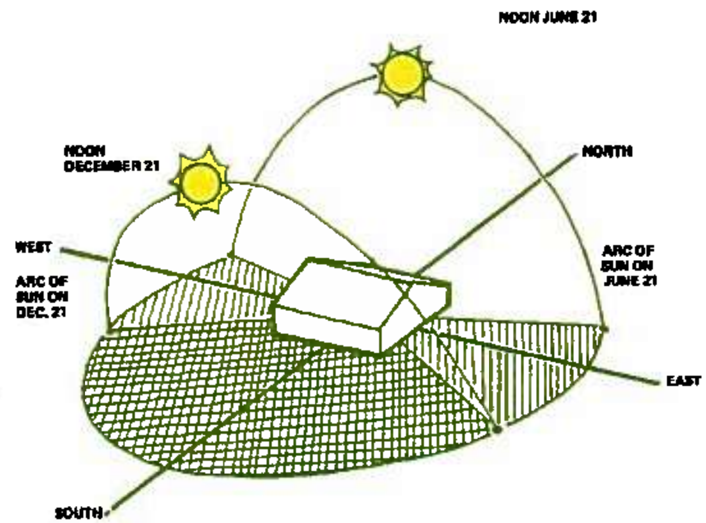
Wind

Location in the trade-wind zone provides predictable wind throughout the year although there are noticeable shifts in the pattern of daily and seasonal velocities. Higher velocity winds occur during the dry season. During the wet season and storm periods, winds may shift from the predominant direction for short periods of time.

The Sun

Sun angles and paths are directly dependent upon a location's latitude. Within the equatorial belt the sun is predominantly overhead. The exact time of sunrise and sunset may vary slightly depending upon a site's location within a time zone.

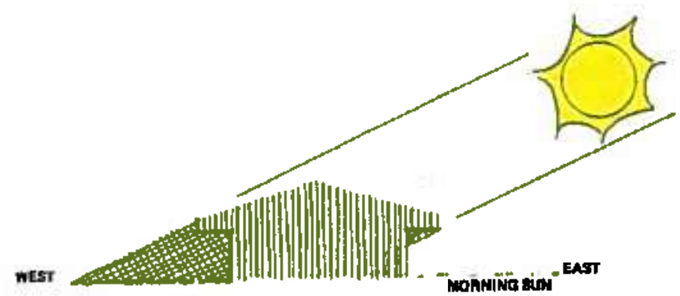
Sun charts will help determine the effect of shadows cast by sunlight falling into a building and the position of the sun at different times of the day and year. In the tropics, it is good design to reflect away, baffle, intercept or absorb the extremes of heat and light to produce a livable interior. The desirable orientation of structures can be predicted based on the inclination of the sun at particular times of the year and throughout the day.

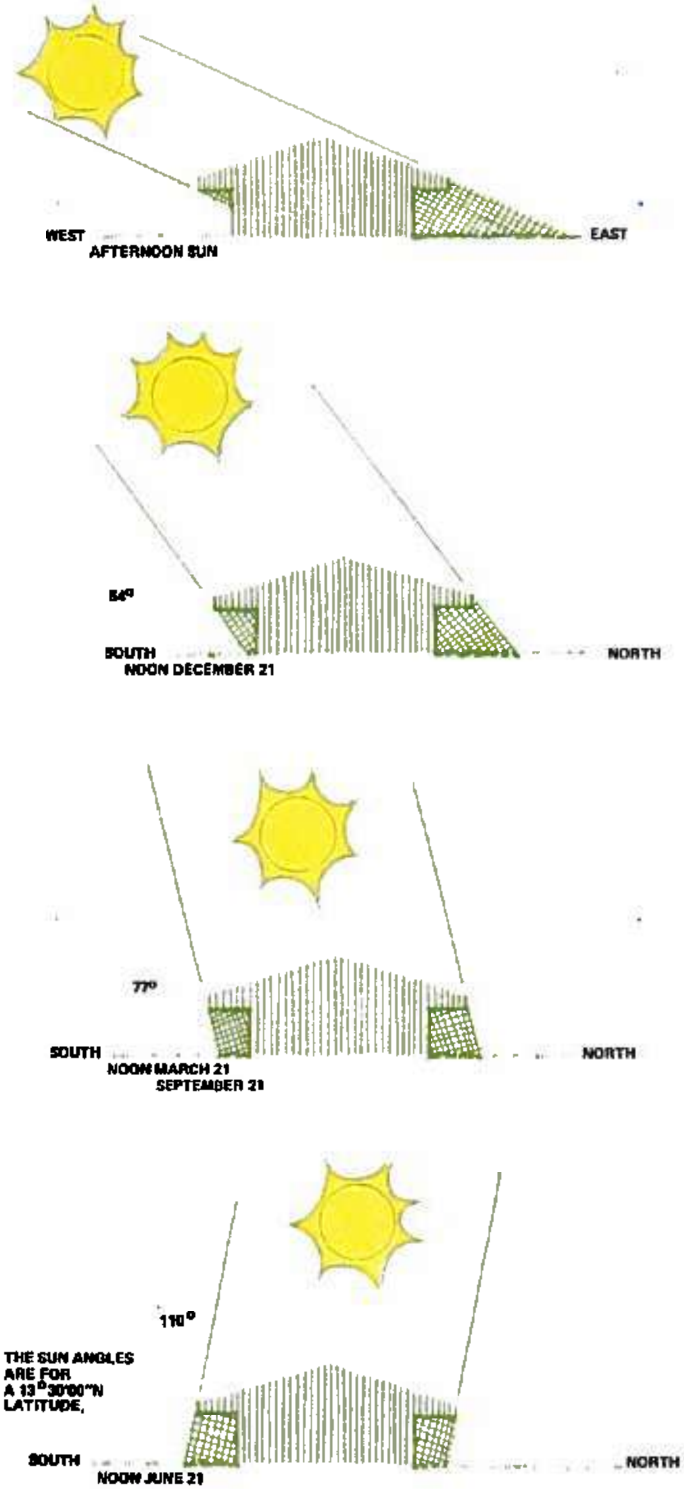


SUN LOCATION

THE EXACT SUN PATHS DEPEND UPON A LOCATION'S LATITUDE. THE DIAGRAM DEPICTS THE SUN PATHS FOR A 13° [illegible] N LATITUDE.

Direct sunlight causes heat load on house walls, heavy on the east and particularly heavy on the west. Overhangs and other protective devices and landscaping should be used to cut down on this direct sunlight. The radiation and a location's temperature are also affected by cloud cover.





Rainfall

Precipitation is a major climatic condition in the tropics. The yearly rainfall is heavy due to the constant availability of moisture-laden air. Rainfall will vary widely from island to island and from year to year. There is a definite local variation due to location and topography with the windward shores and valleys receiving more rainfall and the leeward side of mountains and cliffs receiving considerably less. It is quite common to experience intense rains associated with strong winds at any time of the year. Minimizing the entry of driven rain is important when considering exposure of openings and outdoor living areas.

During the course of the year, shifts in the wind direction, temperature and rainfall are experienced as a result of shifts in the Inter Tropical Convergence Zone. This shift follows the zenith of the sun with about a month delay.

For each general climate there are many specific climatic conditions classed as microclimates. The microclimate is the local deviation due to topography, orientation, elevation, ground surface, vegetation and the presence of three-dimensional objects such as structures, trees, fences and walls that influence air movement and create shades and shadows.

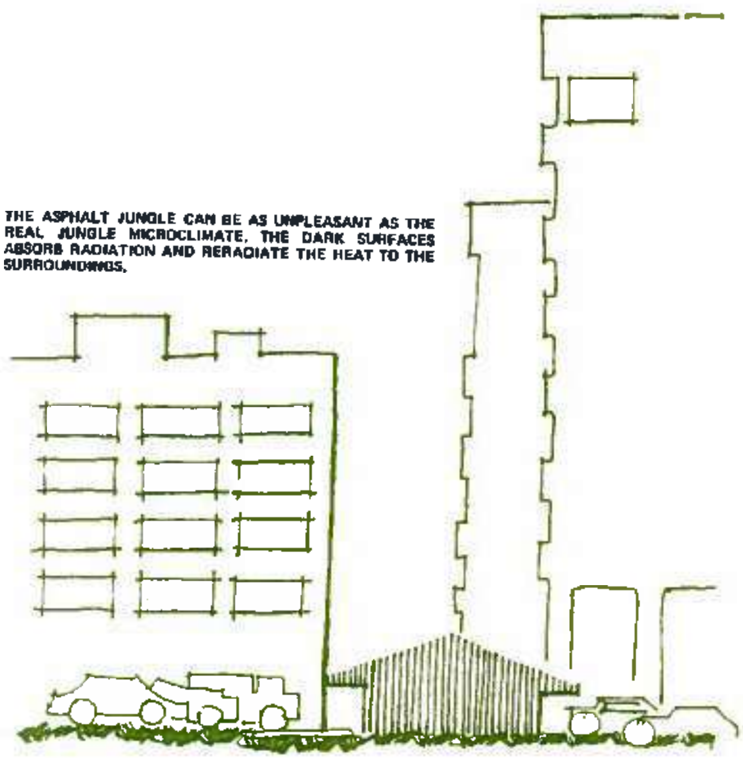
An initial task of the designer is to identify the distinct factors of the site and identify the favorable conditions, constraints and adverse characteristics of the site and its climatic features. The effect of the microclimate is the key for proper selection and planning of a site.

Air temperature is affected by surrounding areas. At any point near the ground air temperature is dependent upon the amount of heat gained or lost by the earth's surface or other surfaces. Additionally, heat exchange near the surface varies from day to night and includes a lag time. An example of lag time occurs when a previously heated surface gradually cools off but continues to emit heat while it cools. During calm days warm air stratifies near the ground surface. At night the ground loses heat by radiation until its temperature is lower than the air and the direction of heat flow is reversed (from air to ground).

The thermal effects of incident radiation depend on nearby surfaces. For ground surface, vegetation is preferable to concrete because the plants diffuse and minimize solar reflections and reradiation. Dark asphalt paving may reach temperatures considerably higher than the surrounding air temperature and reflect or reradiate this heat to persons and structures nearby. With vegetation the surface contact with solar radiation is transferred to a higher layer, thereby allowing the ground to have a cooler layer of air and avoiding the ground build-up of solar heat to be reradiated. Large trees can provide a shade coefficient of 0.20, blocking 80 percent of the sun's radiation to a building or the ground.

Topography affects air temperature and humidity, resulting in a blanket of cool air near the ground. Cool air behaves as a liquid flowing downhill and settles in the deepest depressions. Moist air tends to be heavier so it will seek lower levels, thus creating the cool, damp feeling of a valley. When the moisture-laden air and surrounding damp areas are heated by the early morning sun, the same area often becomes a "steam bath."

THE ASPHALT JUNGLE CAN BE AS UNPLEASANT AS THE REAL JUNGLE MICROCLIMATE. THE DARK SURFACES ABSORB RADIATION AND RERADIATE THE HEAT TO THE SURROUNDINGS.



MICROCLIMATE URBAN SITE

MICROCLIMATES

Dew also tends to form more frequently in valleys. As the lower level of air warms during the day, the ability to hold moisture increases and therefore the RH decreases and the evaporation potential increases. At night the situation is reversed, as air cools, its RH increases and when the point of saturation (100 percent RH) is reached, the excess moisture condenses in the form of dew.

OPEN SHADED AREAS ARE IDEAL FOR THE TROPICS. THE SHADE REDUCES SURROUNDING SURFACE TEMPERATURES. THE BREEZES ARE UNRESTRICTED AND ARE COOLED BY THE SHADED SURFACES.

MICROCLIMATE

MICROCLIMATE

ENSHROUDED IN MOIST VEGETATION, STRANGLED FROM AIR MOVEMENT (AND PROBABLY INFESTED WITH MOSQUITOES), LOWLAND JUNGLE SITES OFTEN FEEL MUGGY AND UNPLEASANT DESPITE ABUNDANT SHADE.

Vegetation affects the microclimate. An open surface of water or rich vegetation will provide an abundant supply of water vapor and therefore will raise the RH. Dense surrounding vegetation will restrict air movement causing stagnant air pockets. High tree foliage provides shade for an area without restricting air flow. Lack of vegetation and an increase in hard surfaces, such as encountered in urban areas, increases the temperature.

Air movement is affected by ground cover and topography. Wind speed is reduced by horizontal barriers such as tree clusters or walls. Also, wind speed increases with the height above the surrounding ground. For hilly sites, the greater wind speed occurs at the crest. In moderately humid areas, valleys are generally cooler than hill crests, but in humid areas, hill crests are usually cooler because of the effect of increased air movement. Valleys and depressions experience low velocities except where the direction of the valley corresponds with the direction of the wind. The more pronounced the valley's form the more the valley's floor will be sheltered from crosswinds and will funnel parallel wind. The effect of nearby buildings is similar to trees as buildings cast shadows, and channel winds with localized increases in velocity and altering of wind direction.

Precipitation is affected by topography and the direction of prevailing breezes. The effect of hills on rainfall patterns can be pronounced, especially where the prevailing tradewinds occur. Where ground level changes significantly, the windward slope will receive more rainfall than the regional average and the leeward will receive correspondingly less. As the hill forces the air mass to rise, the air cools and can no longer support the moisture it carries. Conversely, a descending air mass increases in temperature and can therefore absorb more moisture. This phenomenon is more pronounced with increase in the steepness of the hill formation.

The influence of solar radiation is affected by nearby hills, buildings or trees and surrounding surfaces.

CLIFFLINE SITE

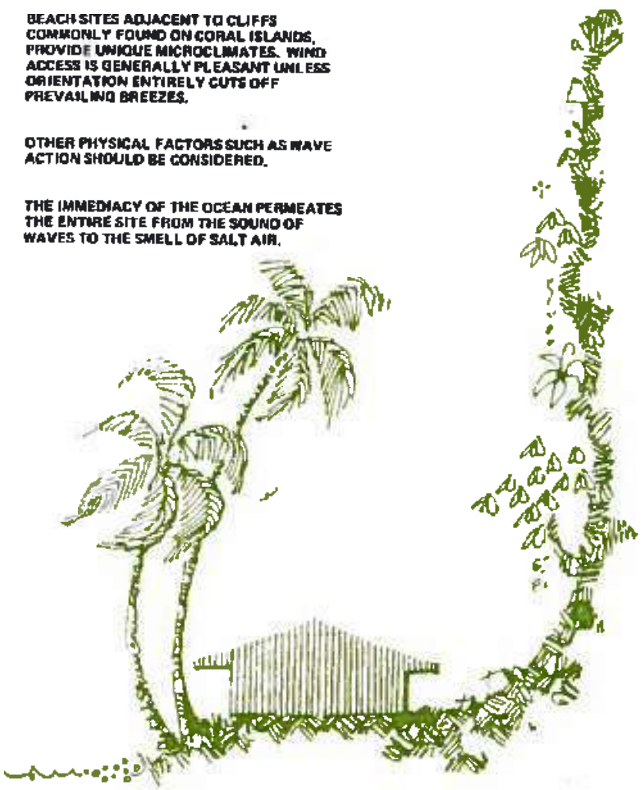
MICROCLIMATE

CLIFFLINE SITES PROVIDE INCREASED AIR MOVEMENT, ARE MORE VULNERABLE TO STORMS AND DEPENDING UPON ORIENTATION MAY BE SUBJECT TO SLIGHTLY GREATER EARLY MORNING OR LATE AFTERNOON HEAT LOADS.

BEACH SITES ADJACENT TO CLIFFS COMMONLY FOUND ON CORAL ISLANDS, PROVIDE UNIQUE MICROCLIMATES. WIND ACCESS IS GENERALLY PLEASANT UNLESS ORIENTATION ENTIRELY CUTS OFF PREVAILING BREEZES.

OTHER PHYSICAL FACTORS SUCH AS WAVE ACTION SHOULD BE CONSIDERED.

THE IMMEDIACY OF THE OCEAN PERMEATES THE ENTIRE SITE FROM THE SOUND OF WAVES TO THE SMELL OF SALT AIR.



These surroundings affect both the shades and shadows cast upon the site and affect the incident radiation. The orientation of surrounding hills and site objects affects the location and direction of shadows. Trees and other structures immediately adjacent to the east and west sides of a site particularly cast long early morning or late afternoon shadows.

OPEN FLATLANDS CAN BE QUITE BREEZY, BUT NEED ADDITIONAL SHADE ELEMENTS.

OPEN FLATLAND

MICROCLIMATE

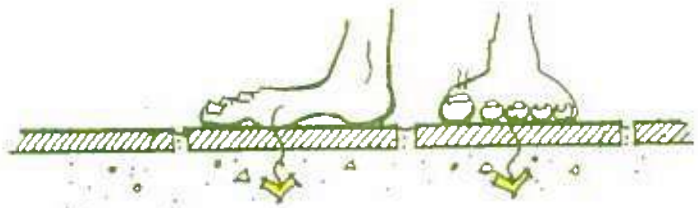
Heat Gain

Heat loads in a space generally come from the outside climate, occupants and equipment or processes (lights, refrigerator, cooking, etc.). The heat is transferred according to physical laws of nature. Heat is generally measured in British Thermal Units (BTU), the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.

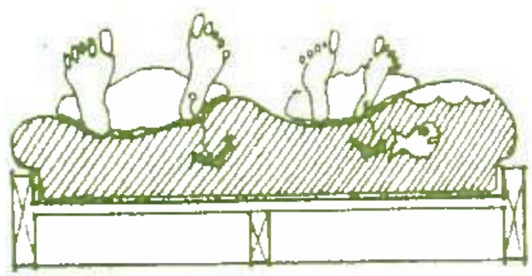
There are four principal ways a body will gain or lose heat: conduction, convection, radiation and evaporation. Loss of heat by the first three can only occur when the air, surroundings or both are at less than body temperature. The heat that is transferred by direct change in temperature is referred to as sensible heat. Loss by evaporation can occur if the air is dry enough to absorb further moisture; the rate heat loss takes place depends on the humidity of the air and the rate the air passes over the body. The transfer of heat is due to a change in state, i. e., from a liquid to a gas, and is referred to as latent heat.

Conduction

Conduction is the transfer of heat through a solid or liquid material, and is dependent upon the temperature differential and the heat flow rate or conductance of the material. Heat transfer through metals is faster than through wood; water stores more heat than wood, etc. Conduction will generally transfer heat much faster than convection. Conduction of heat occurs through contact with cool surfaces such as hard tile floors or waterbeds.



CONDUCTION

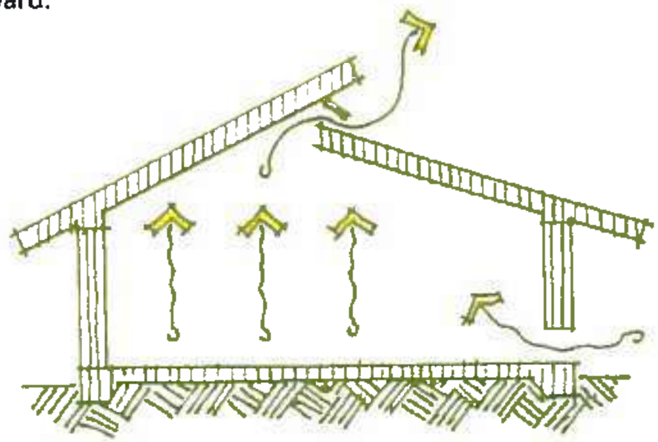


CONDUCTION

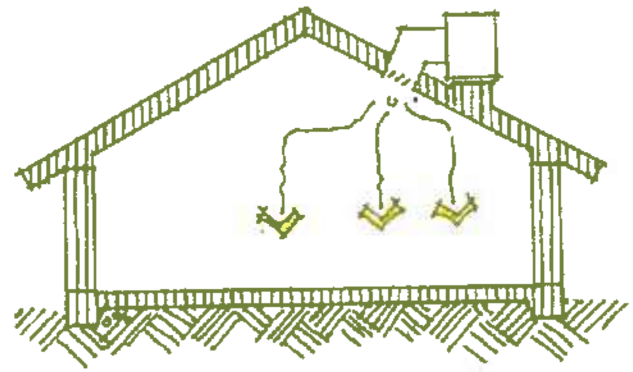
Convection

Convection is heat flow through open air and is dependent on the rate of ventilation and temperature differential.

As a particle of air bumps into another particle of air, heat is transferred. The hotter the air becomes, the more active the particles and the more they expand. The more they expand the lighter the air becomes and it floats upward. Conversely, the colder the air becomes, the less active the particles are and the less space they take; the air becomes denser and sinks downward.



CONVECTION: HOT AIR RISES



CONVECTION: COLD AIR DROPS

Radiation

Radiation occurs through space from a heat source to another object. Radiation travels by various waves with some waves of a visible wave length (light) while others, such as ultraviolet, are invisible. Radiation is a form of energy and often this energy is transformed into heat. In a climate that is already too warm, heat becomes a constant adversary to be managed and controlled in order for people to be comfortable.

A body will give up heat to cool walls or a ceiling even if the air temperature is high. This cooling has a 40 percent greater effect on comfort than air temperature, so lowering the surface temperature 10F (5.6C) would give the equivalent cooling of lowering the air temperature 14F (7.8C).

With a mean radiant temperature of 65F (18.3C) and the air temperature of 85F (29.4C), the effective temperature would be 74F (41C).

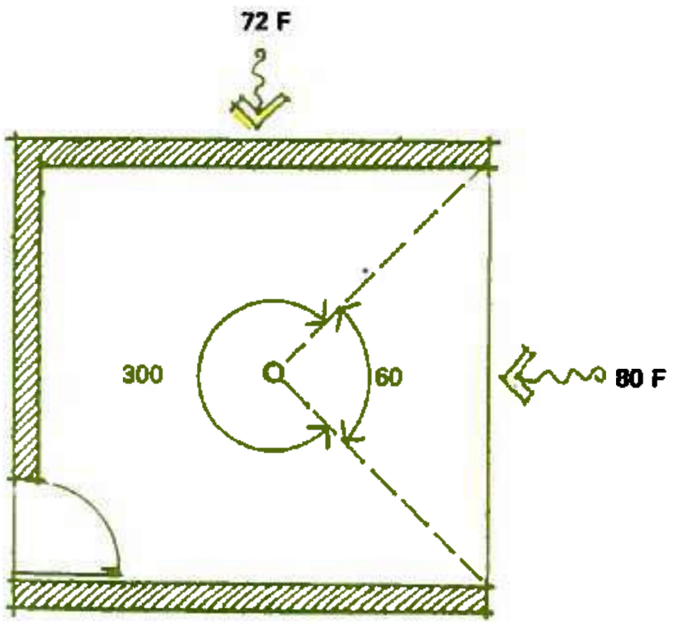
The mean radiant temperature is a weighted average of the various influences in a space as estimated by the following formula:

$$MRT = \frac{\Sigma t\theta}{360} = \frac{t_1\ \theta_1 + t_2\theta_2 + \ldots}{360}$$

MRT = mean radiant temperature

t = surface temperature in F

θ = surface exposure angle in degrees.



RADIANT TEMPERATURE
SPACE DIAGRAM

For example:

$$MRT = \frac{(72F \times 300^{o}) + (80F \times 60^{o})}{360} = 73F$$

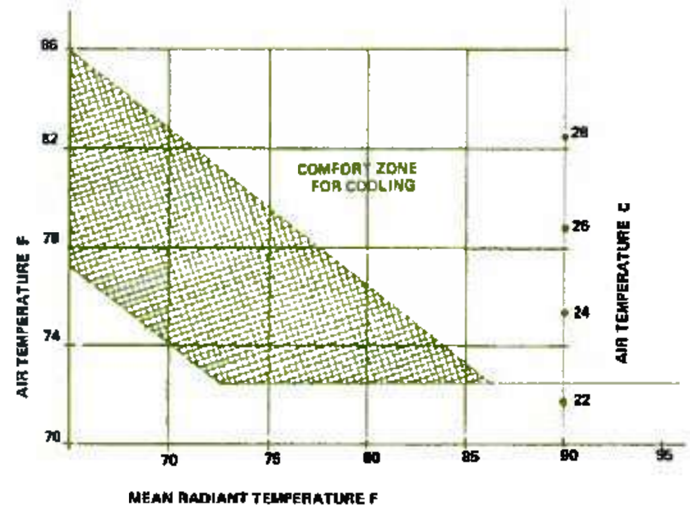
With a mean radiant temperature of 73F (22.8C), air velocity of 20 feet per minute, wearing light clothing and resting an average person can feel comfortable at 80F (26.7C).

For comparison, other examples are listed:

With a mean radiant temperature of 70F (21.1C) and 60 percent RH a person can feel comfortable at 83F (28.3C) air temperature even with minimal breeze.

With a mean radiant temperature of 75F (23.9C) under similar circumstances, a person can feel comfortable at 81 to 86F (27.2 to 30C) depending upon a breeze up to 3.4 miles per hour.

With a mean radiant temperature of 80F (26.7C) and similar circumstances, a person can feel comfortable from 77 to 84F (25 to 28.9C) depending upon a breeze up to 3.4 miles per hour.



AT 60 PERCENT RH and 15 - 60 FEET PER MINUTE AIR VELOCITY
EFFECT OF MEAN RADIANT TEMPERATURE UPON THE
COMFORT ZONE.

At higher radiant temperatures the breeze becomes even more important. With either heavier clothing or more activity the maximum comfortable temperature becomes lower and the breeze even more important. For medium activity, 50 percent RH and a mean radiant temperature of 70F (21.1C) the comfortable maximum is 75 to 76F (23.9 to 24.4C) with a 2.3 to 3.4 mile per hour breeze (200 to 300 feet per minute).

Dense materials like concrete, quarry tile or marble can absorb and store more heat, thus they should be shaded as much as possible. Dense floor materials like marble will absorb more energy and thus retain a cool feeling longer.

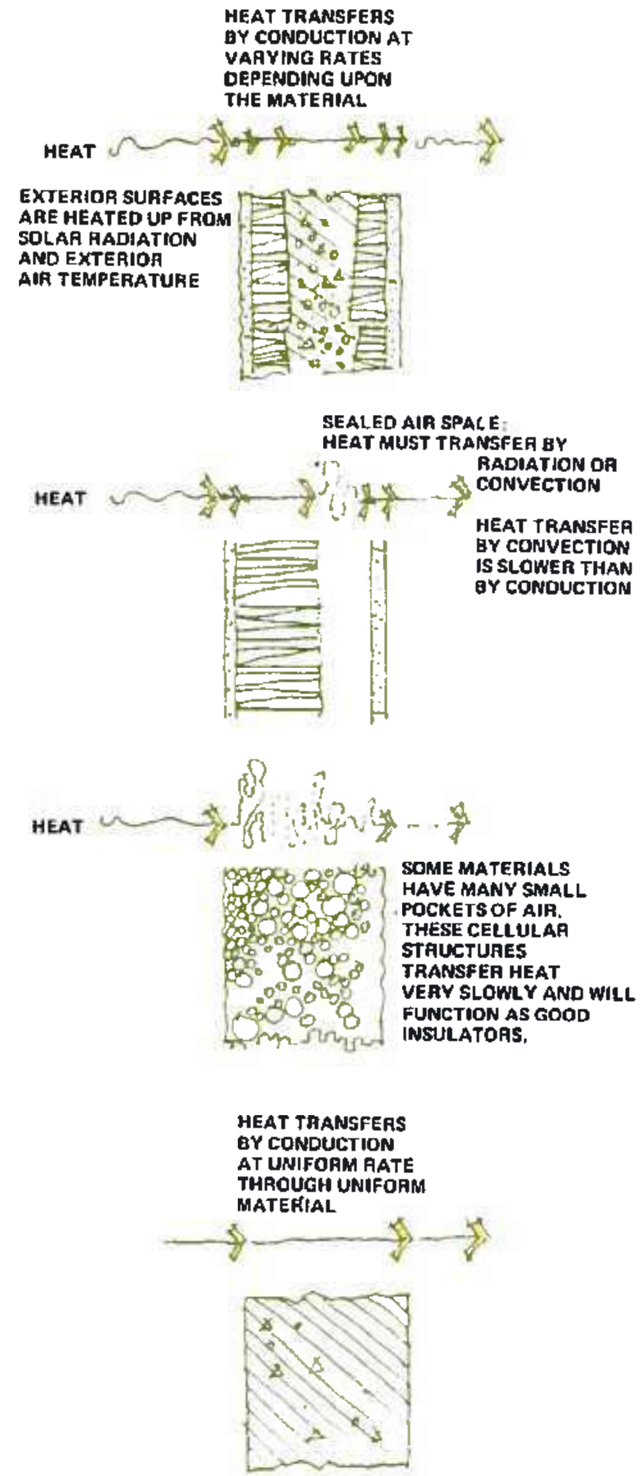
Evaporation

A large amount of energy is absorbed in the physical change of a substance from liquid to gas. This is the basis for almost all mechanical air-conditioning systems, and the built-in human air-conditioning system, perspiration and evaporation.

A moist surface will have greater evaporation if additional air (wind) is moved across it. Thus a person feels cooler in a breeze. Evaporation takes place more readily at low relative humidities rather than high relative humidities when the air is already packed with moisture.

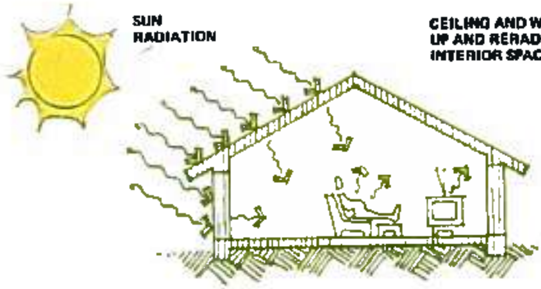
Combined Heat Transfer

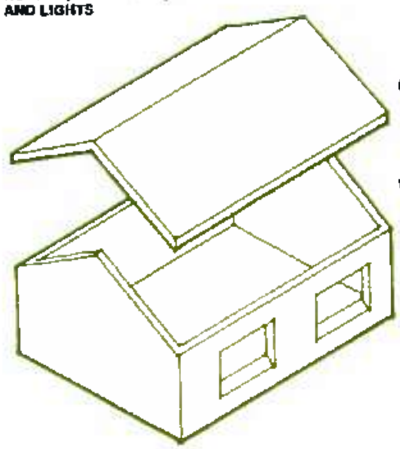
For heat transfer the heat moves from the warmer object toward the cooler object via conduction, convection or radiation. The transfer through building walls will combine these various forms. The heat on the exterior surface will come from radiation and convection. The transfer through the wall will be via conduction and sometimes convection, depending upon the wall configuration and air spaces. From the inside face of the wall, heat is again transferred by radiation and convection.



Building Envelope

The roof, outside walls and floor of an elevated structure are collectively called the building envelope. To determine the heat gain and other thermal effects on a structure, the individual parts of the building envelope are evaluated.





BUILDING ENVELOPE

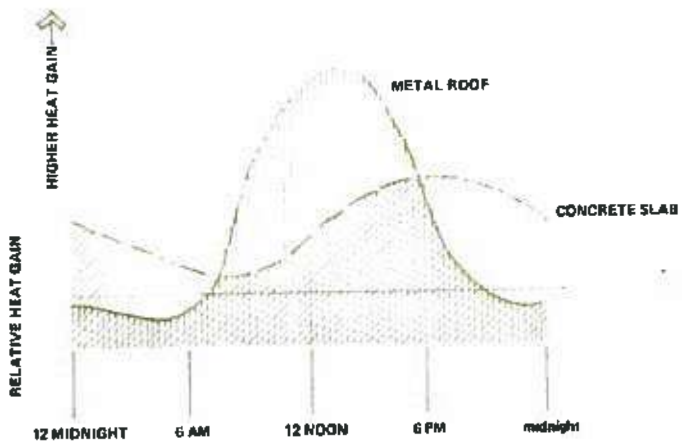
The roof component of the building envelope has the greatest exposure to the sun. Great heat is generated during the day making it necessary to decrease the heat build-up, reduce penetration of the heat to the interior and prevent further radiation of heat to the interior during the night. An unprotected solid roof such as concrete heats up during the day, stores the heat and gets rid of it by radiation or convection at night. An unshaded mass will store four times more heat energy than a shaded mass. With an air temperature of 80F (26.7C), an unprotected concrete slab will show a daytime upper surface temperature of 120F (48.9C) and a lower surface temperature of 115F (50.5C). The better insulated a roof the longer it takes for heat to pass through, and the less heat eventually passes through, as some is reradiated up to the sky. The same principle holds true for walls that are unshaded.

The outside walls form a major area of the building envelope. The insulative values of these walls become very important, especially when the house is to be air conditioned or the walls are exposed to solar radiation. For an elevated floor slab heat transfer is similar to a shaded wall with slightly different factors from the adjacent air films.

In order to compute heat gain for the building envelope, heat transfer values are added for the various materials in a wall or roof. The values depend on the material thickness. Values for the inside and outside air films are also added. Insulating quality of building assemblies is expressed in "R" values. The "R" value is the resistance to the flow of heat measured in time. With an R=20 roof, it will take 20 hours for one British Thermal Unit (BTU) to flow through one square foot of that roof assembly if there is a 1F (.56C) temperature difference between the inside and outside. The appendix provides R values for many typical materials and building assembly calculations.

The inverse of the R value is the "U" value (1/R = U). It is the per hour expression of viewing the same heat flow rate. In the case of the R=20 roof, one-twentieth of a BTU will flow through one square foot of roof in one hour if there is a 1F (.56C) temperature difference. Therefore, the U value of a R=20 roof is .05. Brief calculations for heat gain are indicated below and included in the chapter, Air-Conditioned Houses.

Another heat gain characteristic is thermal lag time; the building's temperature lags behind the outdoor temperature timewise: this is why a west wall feels hot at 10:00 p. m., long after sunset. For example, the interval of lag between the upper and lower surface of a standard 6-inch concrete roof slab is about four hours. Building materials that are dense and heavyweight have longer lag times than thinner, lighter materials. Thermal lag time can be beneficial because it helps even out the interior heat loading and lessens the heat flow since the heat flow is reversed in the evening when the exterior temperature is less than the material temperature.



HEAT TRANSFER TIME LAG (FOR SIMILAR U FACTORS)

Note that the large heat load through a thin roof assembly, metal, corresponds closely with the exterior sun load and temperature. The large heat load through a concrete roof is delayed significantly and is higher at 6 to 7 pm. Actual BTU depends upon actual "U" coefficients.

Lag time is usually not figured into simple heat gain calculations, but is nevertheless an important phenomenon to understand.

To evaluate the transmission through a wall the R values for the various materials along with the R values for the appropriate type of air films are added together. For example:

Concrete block wall without insulation:

outside surface (15 miles per hour wind)	0.17
3/4-inch cement stucco	0.15
8-inch concrete block with cells filled	2.98
inside surface (still air)	0.68
	3.98

$U = 1/R = BTU/hr/ft^2/F = 1/3.98 = 0.25$

This is the amount of BTUs per square foot per degree of temperature change (in Fahrenheit) between inside and outside wall temperature per hour.

A 10-foot by 10-foot wall (100 square feet) with a 15 degree temperature change will transmit in one hour:

$$\text{Heat Load} = U \times Hrs \times Ft^2 \times F$$
$$= 0.25 \times 1 \times 100 \times 15 = 375 \text{ BTU}$$

Note that the exterior surface temperature may be significantly higher than the exterior air temperature because of radiation.

Chapter 2
Design Criteria Part 2
Windows
Shading
General Lighting
Daylighting
Psychological Cooling

Windows

Windows are an important part of the building envelope and their proper design is critical to the livability of a house. Windows have profound psychological influence on occupants and affect the amount of interior light and sense of enclosure. They are vital tools in developing proper ventilation and strategic window placement provides privacy for the interior while offering a variety of views of the exterior.

For proper location, window functions should be divided into three main uses:

Ventilating
Daylighting
Viewing

These uses may be combined but often are more effective with windows that satisfy only one or two functions at a time.

Several other factors are also important to consider:

Safety egress
Minimum heat gain
Rain protection
Security
Maintenance cost
Initial expense
Air infiltration when closed

For minimum heat gain through windows a number of techniques may be used:

Provide reflective glazing, tinted glass or reflective coating.
Control direct sunlight striking or reflecting onto the window.
Locate landscaping for maximum shading.

The following additional methods may be applicable especially when interior spaces are air conditioned;

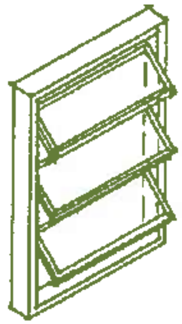
Use minimum ratio of window to wall area.
Provide double glazing, insulated glass or heat absorbing glass.
Face windows north or south, allowing for easier shading.
Reduce air infiltration.
Avoid thermal bridges (seal window frames with gaskets).

The strategies for selection and placement of windows depend upon whether the house is to be naturally ventilated, air conditioned or partially air conditioned. Further explanation of window needs for each type of house is discussed in the individual chapters.

Of all elements, openings give perhaps the most complicated and difficult design task. A well-planned window system will have several types of windows performing several tasks, either individually or interrelated. All types require protection from direct solar radiation, rain, burglars and insects.

The cost of selecting the correct type for each application may be more expensive, but is a very small part of the overall building cost and yet is of great importance to successful ventilation.

Selection of opening types should be based on the importance of each of the window's energy functions, considering climate, orientation, time of day the building is most used and the environmental requirements of activities being housed. The following presents guidelines for choosing the correct type, size and placement of windows. Final selection should be based on consideration of the total opening system, in combination.

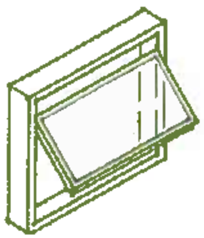


1. 85 to 90%
2. Medium Perimeter

*Should not be installed in traffic areas without side protection. Sometimes hard to seal for security alarm.

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	■		■	■					1	
FAIR		■			■	■				2
POOR							■	■		

AWNING

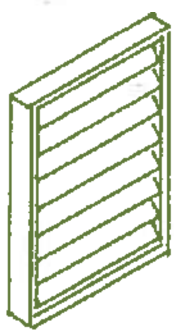


1. Minimun Sealing
2. 40%

*Good for Clerestory windows.

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	■	■		■						1
FAIR	■		■		■	■	■	■	2,	
POOR										

PROJECTING

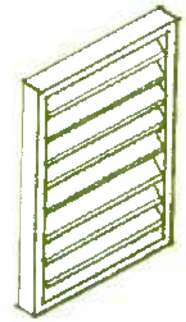


1. 85 to 95%
2. Large sealing perimeter

*Glass louvers inexpensive–aluminum louvers expensive. Louver blades can be glass, frosted glass, aluminum, redwood.

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	■							■	1	
FAIR							■			
POOR		■	■	■	■	■				2

OPERABLE LOUVER (JALOUSIE)

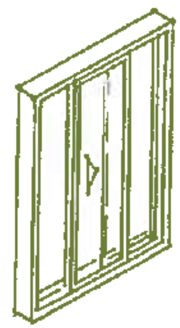


1. 85 to 95%

*Totally incompatable with air conditioning without additional window covering.

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	■						■		1	
FAIR				■		■				
POOR		■	■		■			■		

FIXED LOUVER

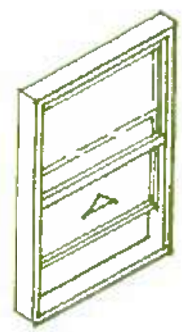


1. Minimum sealing
2. 45%

*Horizontal windows are often more difficult to seal against water infiltration from wind-driven rain.

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD							■	■		1
FAIR	■	■	■		■	■			2	
POOR				■						

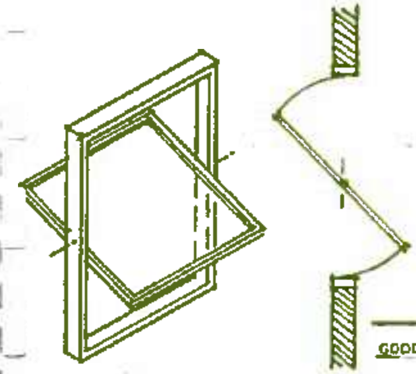
HORIZONTAL SLIDER



1. Mimimum sealing
2. 45%

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD										1
FAIR	■	■	■		■	■	■	■	2	
POOR				■						

VERTICAL SLIDER

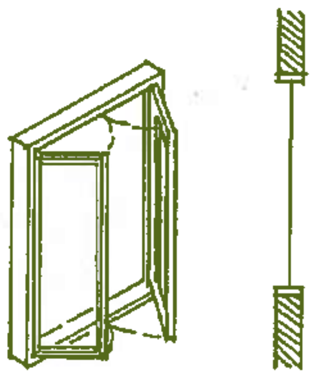


HORIZONTAL PIVOT

1. 95%
2. Minimum sealing perimeter

*Difficult to screen

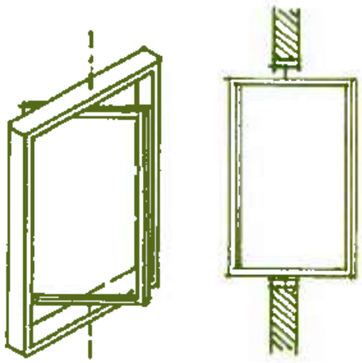
	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	□	□	□		□				1	2
FAIR				□				□		
POOR						□	□			



CASEMENT

1. 95%
2. Minimum sealing perimeter

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	□	□	□						1	2
FAIR				□	□	□				
POOR							□	□		



VERTICAL PIVOT

1. 95%
2. Minimum sealing perimeter

*Difficult to screen

	NATURAL VENTILATION	AIR CONDITIONING	PARTIALLY AIR CONDITIONED	RAIN PROTECTION WHEN OPEN	VIEW	SECURITY	MAINTENANCE	EXPENSE	% OPENING	SEALING PERIMETER
GOOD	□	□	□		□				1	2
FAIR						□	□	□		
POOR				□						

Shading

Shading of windows is an easy and often attractive way to protect openings from direct and indirect sunlight. Shading may be achieved by using exterior appendages. These appendages may be either a part of a window system or part of the adjacent wall system.

In the tropics maximum shade is desired year round, so a simple method of determining necessary dimensions for shading devices is to calculate the minimum angles of shade. If a window is shaded at the time of least angle, then it is amply shaded the rest of the year. These angles vary with the latitude and are different throughout the year. For example, the lowest angle on a southern exposure (in the northern hemisphere) occurs on December 21. Therefore, for December 21, the lowest angle occurring during the main part of the day, 10:00 a.m. to 3:00 p.m., is the governing factor.

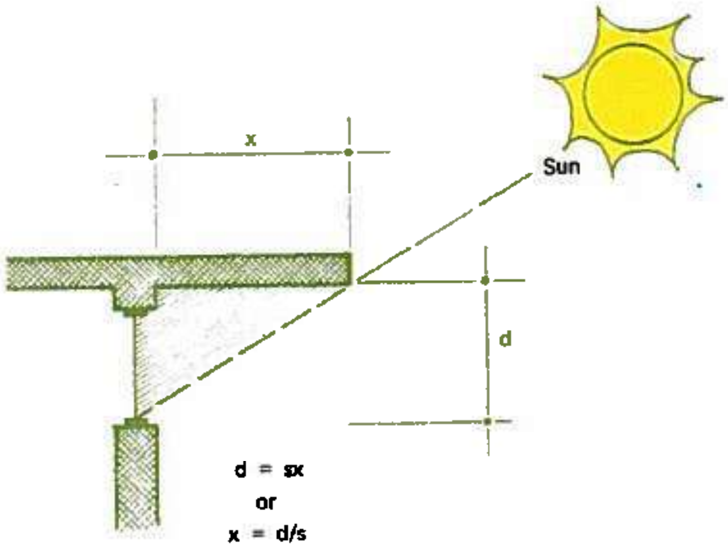
This is an easier approach to shading than employed in temperate climates where part of the year (winter) it may be desirable to have unshaded light for warming purposes.

The following formula determines the amount of shade from horizontal projections where "s" values are derived from the sun angles. The amount of shade from horizontal projections can be approximated using minimim values through the year for the 5 hours of maximum solar exposure, 10:00 a.m. to 3:00 p.m. for a given wall orientation. "s" values for our island are:

E and W wall orientation	0.95
SE and SW wall orientation	0.91
NW and NE wall orientation	3.4
N wall orientation	12.6
S wall orientation	1.13

Fixing the window sill at "d" would mean the window would be shaded year round from 10:00 a.m. to 3:00 p.m.

For east and west walls the critical heat gain periods may be before 10:00 a.m. for east walls and after 3:00 p.m. for west walls. There is a practical limit that horizontal projecting elements can shade these sides and other shading devices listed later on in the section should be considered along with landscaping.

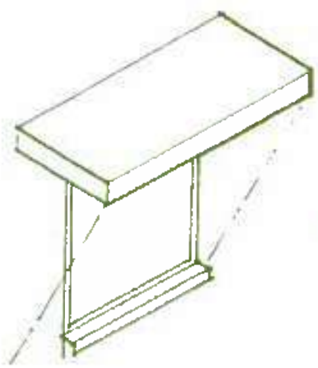


$d = sx$
or
$x = d/s$

The following illustrations compare various shading devices in terms of shading value, ventilation, view, maintenance, cost, initial expense and potential typhoon resistance.

The shading coefficient is the factor that the sky brightness values are reduced due to shading.

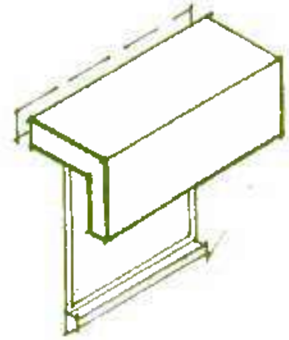
"A" indicates aluminum construction.
"W" indicates wood construction.



	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD					□		□
FAIR	*	□	□	□		□	
POOR							

* 0.25
Very effective for south elevations

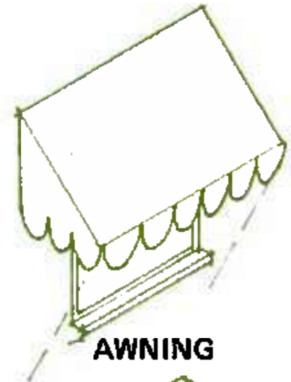
SOLID OVERHANG



	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□			□		
FAIR						□	□
POOR			□	□			

* 0.10

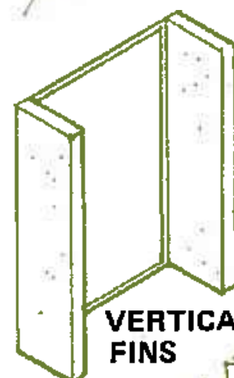
SOLID SCREEN



	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□	□				
FAIR				□		□	
POOR					□		□

* 0.15

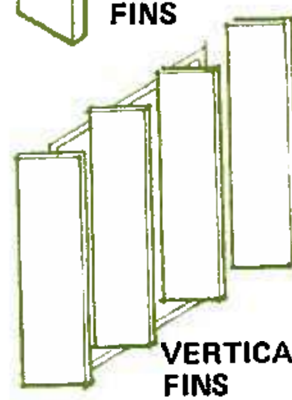
AWNING



	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD				□	□	□	□
FAIR	*	□	□				
POOR							

*.30 to .50

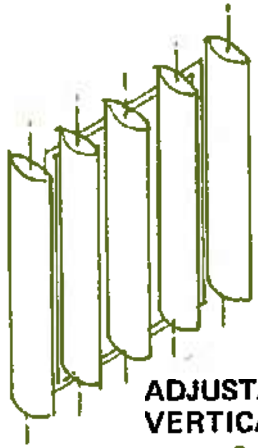
VERTICAL FINS



	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD						□	
FAIR	*		□	□	□		□
POOR							

* 0.30

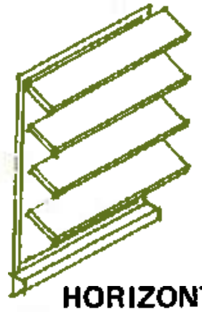
VERTICAL ANGLED FINS



ADJUSTABLE VERTICAL FINS

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□					
FAIR			□	□			□
POOR					□	□	

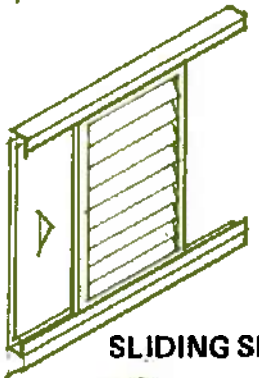
* 0.15 to 0.30



HORIZONTAL LOUVERS

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□				W	A
FAIR			□	□	□	A	W
POOR							

* 0.10 to 0.40



SLIDING SHUTTERS

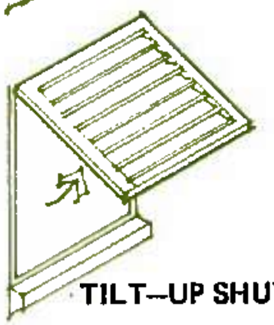
	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□					A
FAIR			□		A	W	W
POOR				□	W	A	

* 0.10

ADJUSTABLE HORIZONTAL LOUVERS

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□					A
FAIR			□	□			W
POOR					□	□	

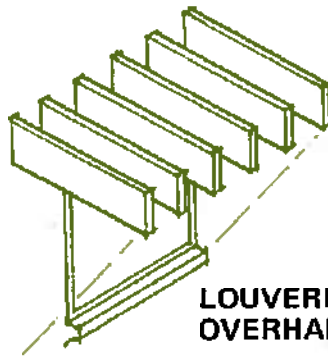
* 0.10



TILT—UP SHUTTERS

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□	□				A
FAIR				□	A	W	W
POOR					W	A	

* 0.10



LOUVERED OVERHANG

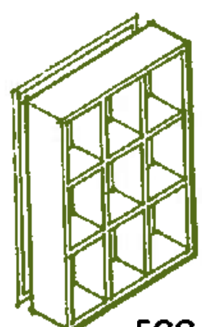
	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD			□	□			
FAIR	*	□			□	□	□
POOR							

* 0.30 to 0.50

SUNSCREEN

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□			□		
FAIR			□			□	□
POOR				□			

* 0.10



EGG CRATE

	SHADING COEFFICIENT	SHADING VALUE	VENTILATION	VIEW	MAINTENANCE	EXPENSE	TYPHOON RESISTANCE
GOOD	*	□					
FAIR			□				□
POOR				□	□	□	

* 0.10